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BORON HIGH-ENERGY FUELS

REPORT

OF THE

COMMITTEE ON SCIENCE AND ASTRONAUTICS
U.S. HOUSE OF REPRESENTATIVES

EIGHTY-SIXTH CONGRESS

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OCTOBER 13, 1959.—Committed to the Committee of the Whole House on the State of the Union and ordered to be printed

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LETTER OF TRANSMITTAL

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND ASTRONAUTICS,
Washington, D.C., September 9, 1959.

Hon. OVERTON BROOKS,
Chairman, Committee on Science and Astronautics.

DEAR MR. CHAIRMAN: I am forwarding herewith for committee consideration a report, "Boron High-Energy Fuels," prepared by Lt. Col. Francis J. Dillon, Jr., staff consultant, and reviewed by members of the professional staff.

The report is based on open session hearings held before the full committee on August 26 and 27 and September 1, 1959.

CHARLES F. DUCANDER,
Executive Director and Chief Counsel.

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OCTOBER 13, 1959.—Committed to the Committee of the Whole House on the State of the Union and ordered to be printed

Mr. BROOKS of Louisiana, from the Committee on Science and Astronautics, submitted the following

REPORT

BORON HIGH-ENERGY FUELS

I. Introduction

On August 26, 27, and September 1, 1959, the committee held open hearings on the nature and effect of the decisions of the Navy and the Air Force not to open the 5-ton-per-day boron high-energy-fuel plants recently completed by the Callery Chemical Co., at Muskogee, Okla., and the Olin Mathieson Chemical Corp., at Model City, N.Y. The committee was interested in determining why it took the services 5 years and over $200 million to decide that they had no requirement for the fuel. The committee was also interested in the plans the services have for the facilities, the future plans in the Department of Defense for research in boron fuels, and the interest of the National Aeronautics and Space Administration in boron fuels and the recently completed production facilities. To determine other possible uses for these facilities the committee called on the two companies concerned.

The committee heard testimony on August 26, 1959, from Rear Adm. R. E. Dixon, Chief of the Bureau of Aeronautics, U.S. Navy, accompanied by Capt. Forrest A. Robie, Executive Director to Assistant Chief for Procurement, Bureau of Aeronautics; Capt. Richard F. Kane, Director of Industrial Planning Division, Bureau of Aeronautics; and Comdr. Rudolph H. Koch, High Energy and Rocket Fuels Branch, Bureau of Aeronautics. The second witness was the Honorable Joseph V. Charyk, Assistant Secretary of the Air Force, Research and Development, accompanied by William Weitzen, Deputy for Research and Development Operations; and Lt. Col. Samuel F. Miller, Deputy Chief, Propulsion Branch, Office of the Deputy Chief of Staff, Materiel. The third witness of the day was Emerson W. Conlon, Assistant Director of Aeronautical and Space Research, National Aeronautics and Space Administration. On August 27, 1959, the committee heard testimony from Dr. W. H. Schechter, vice president, Callery Chemical Co., accompanied by J. S. Bardin, manager of production; Arch Miller, comptroller; and Lloyd U. Cutler, Washington counsel. The second witness of the day was D. J. Carroll Copps, vice president and general manager of the Energy Division, Olin Mathieson Chemical Corp., accompanied by William C. Foster, vice president; Dr. L. Kermit Herndon, divisional vice president; and George Siegelman, director of operations for liquid fuels. On September 1, 1959, the committee heard testimony from John B. Macauley, Deputy Director of Defense Research and Engineering, Office of the Secretary of Defense, accompanied by Donald B. Brooks, Chief, Fuel and Lubricants Division, Office, Director of Defense Research and Engineering.

II. Background

The high energy fuels under investigation are the fuels based on boron hydrides. These fuels are a combination of boron with hydrogen. Then by a process of pyrolysis (the molecular rearrangement by means of heat), and alkylation (the introduction of the hydrocarbon radical into the molecule), the various high energy fuels are formed. The simplest stable boron hydride, diborane, is the major building block for other boron hydride compounds.

Project ZIP was initiated by the Navy in 1952 to develop and produce a fuel for naval aircraft engines with a substantially higher heat value than existing fuels, and to develop means for use of these fuels.

Studies had shown that, by increasing the heat value of the fuel, substantial increases in aircraft range could be achieved, or if the range requirement was held constant a comparable reduction in aircraft size could be realized. While this concept of increased heat value of fuels was known as early as the 1930's, it was not until the late 1940's that the details were established for range increases in the airbreathing engine by the use of high energy fuels.

In 1951 and 1952 the Navy considered the use of higher heat value fuels in the turbojet engine. In November 1951 the Navy made a top secret presentation to the Research and Development Board of the Office of the Secretary of Defense, outlining the potentialities of a fuel based on boron hydride. At that time there were no reasonable grounds for assurance that means other than aircraft would be able to reach targets in the homeland of a potential enemy. Such targets could not be reached by our aircraft without inflight refueling, a then costly and difficult operation. Since the potential gains from the development of such a fuel would be highly rewarding, the Research and Development Board approved the Navy program. Also at the request of the Navy, the Research and Development Board formed a committee, known as the Joint Working Group on Special Fuels, to coordinate, guide and integrate the research and development efforts of the military departments in the field of high energy fuels for piloted aircraft.

In 1952, parallel research contracts were let to Callery Chemical Co. and the Olin Mathieson Chemical Corp. to investigate the borohydrides, their production, and use.

Project ZIP from its inception in 1952 until 1955 was funded by the Navy. In 1955 the Air Force began to sponsor boron hydride research and development and subsequent production at the Olin Mathieson Chemical Corp., while the Navy continued the support of Project ZIP with the Callery Chemical Co. Prior to 1956 the Air Force had been conducting a program on high-energy fuels formed by suspending finely divided metals, such as boron and magnesium, as slurries in a hydrocarbon base. Thus, in effect, the Navy was using the chemical approach to high-energy fuels, while the Air Force followed the physical approach. These programs were complementary and provided excellent coverage of the field without duplication.

At the time the Air Force began support of the program in 1955, there was no indication of the reliability and results that could be expected from the then infant ballistic missile program, for at that time there was no assurance that the United States would have an operational intercontinental ballistic missile when required.

In 1955 there were in existence and functioning only laboratory and bench scale apparatuses for making very small amounts of fuel. The desired compounds had been identified, some of their properties were known, and the chemical processes for manufacturing them had been worked out and tested in small scale.

The most pressing problems were to check the progress data in a larger scale apparatus, to produce sufficient fuel to perform more extensive testing on the fuel itself and to begin designing engine hardware. Thus consideration was given to the production of fuel in quantities large enough to support this engine development.

Project ZIP was considered by a panel of the Killian committee (the Technological Capabilities Panel of the Science Advisory Committee), and a special group of Project Lamp Light (administered by the Massachusetts Institute of Technology) known as the Lamp Wick Group. These studies were based on the recommendation by the Joint Working Group on Special Fuels that an independent review of this work be made. The final report of the Lamp Wick study, classified secret, was issued on March 15, 1955. On the basis of these studies, Assistant Secretary of Defense Quarles recommended to the Navy and the Air Force that steps be taken immediately to initiate a program for the design and construction of two 5-ton-per-day fuel plants, each based on a different process. Mr. Quarles stated:

> The primary purpose of these pilot plants will be to prove the process involved and to provide a sound foundation for the most effective and rapid expansion of production capacity.

As a result of this recommendation, work was initiated on the design and construction of the two plants in June 1956, one being handled by the Navy and one by the Air Force.

Small quantities of boron fuel were required for engineering development and other experimental purposes. To meet these requirements, Callery Chemical Co. designed and built at its own expense a 250-pound-per-day plant at Lawrence, Kans. The cost of this plant was financed in part by a small Navy production order for boron fuel. The experience acquired at the Lawrence plant was of enormous assistance in solving design and production problems at the larger Muskogee plant. At the Olin Mathieson Chemical Corp., three plants—a 40-pound-per-day pilot plant, a 400-pound-per-day pilot plant, and a 1,600-pound-per-day interim production plant—were constructed in the vicinity of Model City, N.Y. The Air Force financed the 40-pound-per-day plant and joined with the Navy in financing the 1-600-pound-per-day-plant. Olin Mathieson built the 400-pound-per-day plant with corporate funds.

In addition to these interim facilities a sodium borohydride plant, operated by Metal Hydrides, Inc., was constructed by the Navy and the Air Force at Danvers, Mass., at a cost of $4,400,000.

When fuel became available in small quantities, early engine tests cast considerable doubt on the ability to attain the improvement in performance which had been estimated from the fuel properties. First estimates of this improvement ranged upward from 50 percent. The most recent studies show that improvement is negligible at subsonic aircraft speeds and quite moderate even at supersonic speeds. In addition, the fuel cost has not been reduced to anywhere near the value expected. In 1954, it was estimated by the contractors that a

fuel cost as low as 60 cents to $1 a pound would be possible at a moderate level of production. The estimates for the 5-ton-per-day plants, which are under discussion, are in the vicinity of $5 a pound after the plants have been brought fully onstream. With improved processes and larger scale production, the cost might be brought below $2 a pound.

The National Aeronautics and Space Administration conducted numerous tests on boron fuels in jet engines and found that—

(*a*) Boron fuels decompose at high temperatures and tend to form a solid before complete burning. This problem was solved by designing fuel injection nozzles which mix air with the boron fuel.

(*b*) The products of combustion of boron fuels (boric oxide) are in a liquid form below 3,000° F. As the temperature decreases, this liquid becomes like a glue, which adheres to the various parts of the engine, and at about 850° F. becomes a solid. The formation of this deposit on the turbine is similar to the formation of ice on the wing of an airplane. The first test demonstrated that a turbojet engine would lose power rapidly after a short period of operation. Research on component parts demonstrated that this problem could be solved by increasing the temperature of the engine and making certain other modifications. However, considerable work remains to be done, and full-scale engine tests over a wide range of operating conditions would have to be made to obtain a satisfactory turbojet for boron fuels. The problems of using boron fuels in afterburners and ramjets were much easier to solve.

(*c*) Experiments on a full-scale afterburner indicated that, if the operating temperature was raised from 2,500° to 3,000° F., a 10- to 12-percent loss of energy occurred. At 3,000° F., the boric oxide did not condense while passing through the nozzle, and the energy corresponding to the heat of vaporization was lost. Modification of the design of the nozzle tended to minimize this problem.

(*d*) The boron fuels are toxic and are subject to decomposition at high temperatures. As a result of considerable research by several agencies, solutions were found to these problems and data necessary for designing satisfactory fuel systems for aircraft were obtained. Results from the research program demonstrated that satisfactory ramjets and afterburners can be developed.

At the time that the decision to proceed with the 5-ton-per-day plant was made, the planned long-range strategic bomber, later to become the B–70 *Valkyrie*, had emerged as the leading prospective user of this new fuel. In order to provide fuel for the timely development and qualification of the B–70 jet engine, the 5-ton-per-day plant had to be started. The engine selected for the B–70 was the General Electric J–93. The Air Force initiated development on a version of this engine, known as the J–93–5, to utilize boron fuels in the afterburner. The advanced Bomarc was another potential user of boron fuels, but this did not become an active program.

Project ZIP was reviewed by a board convened by the Chief of Naval Operations in March 1957. The board concluded Project ZIP to be a research and development program to prove the feasibility and practicability of a ZIP-burning turbojet, ramjet and afterburner. The board also recommended the continued construction of the Muskogee 5-ton-per-day plant.

In late 1957 and early 1958 the NACA test results disclosed the magnitude of the problems to be overcome in order to use this fuel

in all jet aircraft. It was considered feasible to use this fuel in ramjets and turbojet afterburners.

In 1958, emphasis in the Navy shifted from high performance attack and fighter aircraft to slower aircraft that were to perform as platforms for high-performance missiles. This shift of performance requirements to the missiles resulted in a reorientation of Project ZIP toward applications for missile propulsion. With this shift of emphasis, the Navy requirement for high-energy fuel was reduced to approximately 25 percent of the Muskogee plant production.

After informal talks, the Navy invited the Air Force to participate in the Muskogee production in December 1958. The Air Force declined, but invited further discussion. Again the Air Force was invited to participate and again declined in April 1959.

During 1958, it became apparent that some of the boron fuels R. & D. objective would not be met. Also aerodynamic and structural improvements in the B–70 have indicated that adequate performance may be obtained without the use of high energy fuels.

As pointed out by the witnesses from the Office of the Secretary of Defense and the Air Force, the operating cost of the B–70, utilizing 40,000 pounds of high energy fuel in the afterburner for 1 hour at a cost of $5 a pound, would be $200,000. This is compared to a cost of 2 cents a pound or $800 an hour using hydrocarbon fuels as presently planned.

These indications caused the services to reconsider their programs quite carefully. In June 1959, the Chief of the Navy Bureau of Aeronautics recommended termination of the Muskogee production contract, but recommended that the concurrence of the Secretary of Defense be obtained prior to termination, owing to the scope of the program and the national defense aspects involved.

In June 1959, the Director of Defense Research and Engineering initiated an engineering study of the capabilities of the two 5-ton-per-day plants with Arthur D. Little, Inc. The results of this study are to be reported at a meeting of the Joint Working Group on Special Fuels on September 10, 1959. As soon as possible thereafter recommendations will be made regarding the future of the different plants.

As the Air Force decided to terminate the development of the J–93–5 engine for the B–70, and the advanced Bomarc did not become an active program, there were no development requirements for the quantities of fuel which the 5-ton-per-day plant is capable of producing. Therefore the Air Force directed that the Olin Mathieson Chemical Corp. discontinue fuel plant operations for the 5-ton-per-day plant. This action affected only the use of high-energy fuel in the B–70, and the engine and fuel plant programs which supported that application.

The program costs are as follows:

NAVY

Research and development (includes ramjet engine)	$53, 000, 000
Muskogee high energy fuel plant construction	35, 000, 000
Muskogee high energy fuel plant startup costs	9, 000, 000
Other fuel production	7, 000, 000
Fuel production facilities (other than Muskogee)	3, 000, 000
Research and development facilities and unexpended balance of obligated funds	16, 000, 000
Total	123, 000, 000

AIR FORCE	
Process development	$23, 300, 000
Facilities	53, 300, 000
5-ton plant startup costs	9, 700, 000
Sodium borohydride for the 0.8-ton plant	7, 000, 000
Fuel from the 0.8-ton plant	6, 500, 000
Fuel from the company-operated plant	6, 300, 000
Fuel from Callery	1, 000, 000
General Electric J–93–5	8, 700, 000
Marquardt RJ–43	4, 400, 000
Total	120, 200, 000
NASA	
Research and development	3, 500, 000

III. The Hearings

Testimony before the committee indicated that in any program of scientific research, particularly in the military field, it is often necessary to explore simultaneously various methods of accomplishing a particular objective. In the beginning no one knows which method will prove to be the best. Progress made in pursuing one method often stimulates progress in competing methods. And it often happens that several of the methods pursued to achieve one objective produce basic knowledge that becomes of even greater value in pursuing another objective.

This research and development philosophy can be applied to almost any field of scientific endeavor. The accumulation of scientific teams by the two services for research in high-energy fuels was a bold step forward in preserving the free world. These teams, utilizing the experience and research facilities of two dozen universities and thirteen companies and research institutes endeavored to obtain more heat per pound of fuel than existed in the hydrocarbon fuels. Such energy potential would allow military aircraft to carry smaller fuel loads to obtain the same range, carry the same fuel load, and make greater ranges, or drastically change the design performance specifications of new aircraft.

In a number of ways these objectives were met. For some years, during the research and development period, it appeared that the desired performances would also be met. However, with changing times and new methods of warfare, technology has passed them by. A weapons reevaluation caused the Navy to reduce its emphasis on high-speed aircraft and rely on low-speed, missile-carrying aircraft to accomplish some of the assigned missions. The Air Force was also faced with a decision regarding the performance of the B–70, *Valkyrie*, bomber now being developed. Recent tests showed that the aerodynamic performance of the B–70 exceeded the original performance estimates, and the range increase provided by the boron high-energy fuels was no longer required to meet the operational objectives. The cost of the boron fuels also added complexity to the problem. When the program was initiated in 1956 cost estimates were on the order of 60 cents to $1 for 1 pound of fuel. Recent estimates show that the cost will be approximately $5 a pound for the initial R. & D. production plants, with projected large-quantity production costs at about $2 per pound.

As a result of these operational, financial, and technical considerations, the services determined that there was no requirement for the volume of high-energy fuel that was to be produced from the newly constructed plants at Muskogee, Okla., and Model City, N.Y. Termination orders were transmitted to the Callery Chemical Co. and Olin Mathieson Chemical Corp. in August 1959 at approximately the same time full production was due to start at both 5-ton-a-day facilities.

This termination had a severe impact on both companies and an even greater effect on the workers and the communities involved. In Muskogee, Okla. the 463 people employed by Callery Chemical Co. made up over 20 percent of the total industrial payroll. The sudden termination of the Muskogee contract has destroyed this community buildup, threatened the savings and homes of the individuals, and injured the morale of Callery's entire technical staff.

A similar situation exists at the Olin Mathieson facility at Model City, N.Y., where termination affects over 1,000 employees. There, at the Model City complex, Olin Mathieson had 752 people working in the full-scale 5-ton-per-day production plant, plus 83 in the interim production plant, 103 in pilot plants, and 127 in research and development activities. Olin Mathieson is making efforts to plan the integration of these people into its operations in other locations, but it must be appreciated that this is not easy or always practical.

Of prime importance to the committee is the reason why it took the services 5 years and over $200 million to determine that they had no requirement for the fuel. Some members of the committee believe that it is a tragic mistake, that someone should answer for a mistake of this magnitude, and that the taxpayers cannot afford the luxury of these mistakes.

Testimony indicated, however, that the decision to shift emphasis away from the boron fuels for turbojet aircraft was due to a number of factors which gradually developed over a long period of time. Among these were the improvements in the ballistic missile program, the shift of emphasis from manned aircraft to missiles, increased aerodynamic performance of aircraft in development, the relatively high cost of boron fuels compared to the cost of hydrocarbon fuel, and in general because it became more apparent that some of the early promises of boron fuel would not be realized on a timely and economic basis. According to the testimony, the most important factor in the recent decision was the increased performance of the B–70 by means related primarily to structures and aerodynamics. Range requirements for the B–70 can be met without the use of high-energy fuel in the afterburner. The Air Force witness indicated that the performance increase in the B–70 was made in the last few months,[1] and steps were then taken to cancel the J–93–5 engine, which is the model of the J–93 that would use boron fuel in the afterburner. As this engine development program was the prime user of the Olin Mathieson 5-ton-per-day boron-fuel plant, steps were simultaneously taken to close down that plant. If the B–70 range requirements had not been met with hydrocarbon fuels, it is conceivable that there would be a need for all the capacity that exists in the country for high-energy fuels at this time plus additional larger capacity plants.

[1] NOTE.—Witness refers to April, May, and June 1959.

Testimony indicated that the two high-energy-fuel plants were to supply fuel for an engine research and development program and that the facilities were not for production of fuel for the operating forces.

Some committee members spoke in support of a broad research and development program in the United States. It was stated that when a project is initiated, it is inherently impossible to predict with certainty whether the gamble will pay off but that the starting of such a program is justified because such programs in general are necessary to further progress. The expense of R. & D. is high, but it is realized that defenses must be kept up to preclude the necessity for spending additional millions in catching up. The committee has to be critical of scientists, but it also has to protect scientists and the people who do R. & D. work, and to stand between them and undue criticism.

In the case of boron fuel research it was pointed out by a committee member that these expenditures may not be a total loss but might justly be charged against some future R. & D. program. Testimony indicated that only the future can really tell what money has been profitably spent and what money we could have avoided spending. In this case experience and knowledge have been gained about fundamental combustion processes which may have application to a number of fields.

Continuing its investigation, the committee looked into the plans that the services have for the facilities, and the future plans of the services and the National Aeronautics and Space Administration for research in boron fuels.

Witnesses pointed out that there is no requirement, at the present time, for the amount of high-energy boron fuel that can be produced by the two recently completed 5-ton-per-day plants. The services have searched for a use of these facilities, but the unique process is very difficult to adapt to other requirements in the Department of Defense or commercially. The amount of boron fuel used by the NASA in their research program is small and therefore the NASA has no requirement for the two 5-ton-per-day boron fuel plants.

The Director of Defense Research and Engineering, Office of the Secretary of Defense, concurred in the Navy and Air Force decisions to terminate production of high-energy fuels at the two facilities. Earlier, when it became apparent that one of the two plants probably would be closed down, the Director of Defense Research and Engineering negotiated a contract with Arthur D. Little, Inc., for an engineering study of the capabilities of the two 5-ton-per-day plants. The results of this study are to be reported at the meeting of the Joint Working Group on Special Fuels on September 10, 1959. As soon as possible thereafter recommendations will be made by the Director of Defense Research and Engineering regarding the future of the plants. Testimony further indicated that a research and development program will be formulated at the September 10, 1959, meeting which will unquestionably use some, though not necessarily all, of the facilities and personnel of the smaller plants.

It was pointed out in testimony that the high-energy-fuel program has not been terminated. There is presently underway an active R. & D. program in the application of boron compounds to rocket propellants, and advanced ramjets. As part of the studies underway by the services, a review of fuel requirements and sources of

this fuel is being made. This is in addition to the Arthur D. Little, Inc., study for the Director of Defense Research and Engineering. The Air Force presently has contracts with Reaction Motors Division of Thiokol Chemical, with Olin Mathieson, and with the U.S. Borax Corp. aimed at the exploitation of boron compounds for high-energy solid propellants. They also have contracts with the Rocketdyne Division of North American Aviation, Inc., and with the Aerojet-General Corp. aimed at storable liquid propellant rocket systems, and with a combination of Aerojet-General & Stauffer, with Callery Chemical, with a combination of American Potash, Food Machinery, National Distillers, and also with Olin Mathieson in regard to process studies for the production of boron-type fuels.

The Navy applications for the future of boron fuels now rest with continued development of compounds and systems revealed only recently; these are in the field of liquid monopropellants, additives for solid propellants, and other boron compounds. These fields are being investigated at a level of effort considered appropriate to the progress made.

However, testimony indicated that, although work has been underway on boron for solid propellants, more experimental data are required. Considerable work is required on the formulation of solid propellants using boron-hydride compounds. These boron-compound fuels will then be compared with other fuels to determine the best missile fuel.

Fuel requirements for the entire research program for the next 2 years were estimated at approximately 500 tons. Such a small amount can be produced by the Government-owned 1,600-pound-per-day plant at Model City, N.Y., and the Callery Chemical Co. plant at Lawrence, Kans.

Some committee members were concerned over the possible loss of the scientific teams brought together over the last 10 years for research on boron fuels. The Government, as well as the companies, has a real stake in these teams. Committee members indicated displeasure over the delay regarding the final decision on the two facilities in question. Although a decision will be made as soon as possible after the September 10, 1959, meeting of the Joint Working Group on Special Fuels, some members consider this time too long and want a prompt decision on the future of boron-fuel research. It is the feeling of some members that if this decision is made promptly the scientific teams will not deteriorate but will be ready to take an active role in any future boron-fuel program. Committee members want assurance from the Department of Defense that the scientific teams will be saved, if possible, so that the money already spent will not be entirely lost. These teams are composed of people who must insure a future for their families and cannot wait indefinitely while their future is being determined.

Some committee members indicated considerable dissatisfaction with the organization of the Department of Defense and the management techniques employed in making decisions with respect to the high-energy-fuel program. As one member stated, "It seems to be impossible to determine specifically the responsibility for given programs and who finally has the right to say yes or no."

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IV. Conclusions

Although the committee hearings were scheduled on short notice, the witnesses covered the field of boron-fuel research, development, and production from the executive-management level. Thorough interrogation by the committee members emphasized important facts regarding the termination of the boron-fuel production program at the two new 5-ton-per-day facilities. The committee did not investigate the development of engines which use boron fuels but limited its investigation to the production facilities, which were terminated, and the future use of boron fuels. In summary, the hearings showed that—

(*a*) The services were justified in terminating the originally programed production at the two 5-ton-per-day boron-fuel plants due to the change of requirements which resulted from technological advances attendant with the missile and space age.

(*b*) The Department of Defense was slow in recognizing changing requirements for high-energy fuels. As a result, the total cost of the program was substantially increased, and the impact of termination was heavier on the industries and communities concerned. Blame for this delay, from the time in 1958 when it was technically apparent that the two large plants were no longer needed until action was finally taken by the Department of Defense, rests not on the derelictions of any individual or single office, but upon the whole cumbersome process of decision-making in the Department.

(*c*) The committee recognizes that if the decision to close the production facilities had been made early enough, considerable money would have been saved. However, cutoff of the construction in the final stages could not reduce expenditures appreciably and completion of the facilities was perhaps warranted once that late stage had been reached.

(*d*) A firm national program for boron-fuel research is needed immediately to preserve the scientific teams now in existence. The committee recognizes the efforts underway by the Navy and the Air Force for future application of boron fuels, but believes that an integrated national program is required. Prompt action should be taken by the military services and NASA to initiate this program.

(*e*) There is a continuing requirement for certain boron compounds, primarily in connection with the rocket propellant program; however, these may also be used in ramjets if a requirement for this type of engine is established. The several smaller plants already operating are sufficient to meet these needs today without the help of the two 5-ton-per-day plants.[1]

(*f*) Development of missiles and space vehicles has recently begun to take precedence over the development of aircraft. This was one of the major considerations in the termination of research on aircraft engines using boron fuels. The unexpectedly high costs of the boron fuels, coupled with difficulties of applying them and the small incre-

[1] This conclusion, arrived at from testimony presented during the hearings (p. 8), does not agree with the "Recommendations of the Joint Working Group on Special Fuels" (p. 12) which states:

"At the present time no firm requirement exists for the operation of either of the 5-ton-per-day plants. However, the future prospects for boron fuels in rocket uses are at the present time considered sufficiently promising to warrant retaining a capability of producing such fuels on a scale of up to 5 tons per day. The great uncertainty that there will ever develop a need in excess of this level, coupled with the recognition that other more efficient processes are under development and should be available within the next several years, leads to the conclusion that one of the two 5-ton-per-day plants should be declared surplus and available for disposal."

ment of speed or range obtained, were important contributing elements to the decision to abandon the original program.

(*g*) Termination of these two production facilities for boron fuels has had a tremendous effect on the workers, communities, and scientific teams of the companies concerned. All possible efforts which are consistent with national needs should be made to find useful alternative employment for these workers, facilities and research teams.

(*h*) Information acquired in the research program on high-energy fuels for jet engines will have application to the solid and liquid rocket propellant research program. The funds expended cannot be considered a total loss, but only the future can tell what has been profitably spent.

(*i*) The committee heard of no other use for the two 5-ton-per-day production plants at this time. The services are surveying for possible commercial as well as military uses. A possible use is the conversion of the facilities and the production of more advanced propellants for research and development uses.

(*j*) The method of handling research and development of high-energy fuels in the Department of Defense has indicated the need for reorganization which will provide better management of programs of interest to more than one service.

(*k*) The committee fully realizes that these boron fuel production facilities were in support of a highly speculative research and development program and does not desire to make any statement which will affect any national research and development program.

APPENDIX

OFFICE OF THE DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING,
Washington, D.C., September 11, 1959.

RECOMMENDATIONS OF THE JOINT WORKING GROUP ON SPECIAL FUELS IN REGARD TO HIGH ENERGY FUEL PRODUCTION PLANTS

The Joint Working Group on Special Fuels met in Washington on September 10, 1959. Representatives of Arthur D. Little, Inc., presented an oral report on their study of the capabilities of the five fuel facilities. Their complete report, in written form, will be available the week of September 21. The Air Force and the Navy gave presentations on their current research plans and fuel needs.

After thorough consideration of these presentations, the Joint Working Group took action on the following basis: Maximum quantities possibly needed during the next 5 years were estimated by the Joint Working Group from the stated needs for fiscal 1960 and the described service programs. If these programs yield attractive findings, the total needs for various boron type fuels may increase from the immediate level of 180,000 pounds per year to a possible maximum of 5 million pounds per year (output of one 5-ton-per-day plant) by the end of this period.

There is, of course, no certainty that this maximum will be reached. If incorporating boron hydride derivatives in rocket propellants should not prove attractive, all needs could virtually cease in a very few years. Interest in boron type fuels for air-breathing powerplants has about disappeared. No plans exist for their use in manned turbojet aircraft, and only a relatively minor possible use remains should they be adapted to ramjet propelled missiles. The maximum needs foreseeable are well within the capability of one 5-ton-per-day plant.

On the foregoing basis the Joint Working Group on Special Fuels submits the following conclusions and recommendations:

I. STANDBY PRODUCTION CAPACITY

At the present time no firm requirement exists for the operation of either of the 5-ton-per-day plants. However, the future prospects for boron fuels in rocket uses are at the present time considered sufficiently promising to warrant retaining a capability of producing such fuels on a scale of up to 5 tons per day. The great uncertainty that there will ever develop a need in excess of this level, coupled with the recognition that other more efficient processes are under development and should be available within the next several years, leads to the conclusion that one of the two 5-ton-per-day plants should be declared surplus and available for disposal.

A review of all factors leads to the conclusion that the Muskogee 5-ton-per-day plant should be retained and the Lewiston 5-ton-per-day plant declared surplus. The following factors are pertinent to this conclusion:

1. Under both ultimate and reduced capacity the Muskogee plant will produce diborane (80 percent of total fuel cost) at a cost less than the Lewiston plant.

2. The Muskogee plant has greater flexibility for intermittent operation and for operations at less than rated capacity, as may well be required during the next several years. Whereas the Muskogee plant can run as low as 10 percent of rated capacity, the Lewiston plant is inoperable below 35 percent.

3. The Muskogee plant has been advanced to a greater state of readiness. At least 3 months of startup operations, costing $4 or $5 million would be required to bring the Lewiston plant to the level now attained by the Muskogee facility. Further, the costs of restoring the Muskogee plant to operating condition following a period of standby would be substantially less than for the Lewiston plant.

4. Although the Muskogee plant does not now have the capability to produce the fuels desired for rocket purposes (pentaborane and decaborane) as does Lewis-

ton, these can be added at Muskogee at a fraction of the cost differentials referred to in paragraph 3 above.

In anticipation of a continuing need for boron fuels engineering studies should now be undertaken to ascertain the costs and other factors associated with converting the Muskogee facility from a jet fuel to a rocket fuel basis. In this connection, arrangements should be made for Government-financed know-how on production of pentaborane and decaborane to become fully available for these studies. Consideration should be given to the transfer of pentaborane and decaborane manufacturing facilities from the Lewiston to the Muskogee facility. A decision as to whether to install the fuel facilities at Muskogee should be deferred pending completion of the engineering studies and further clarification of forecast fuel needs.

II. INTERIM PRODUCTION OF BORON FUELS

There exists indicated unfilled requirements through 1960 for 150,000 pounds of pentaborane and 6,000 pounds of decaborane. It is clear that at least the bulk of this requirement must come from facilities now in being. This dictates that the 0.8-ton-per-day plant at Lewiston be operated to supply these needs, using the substantial amount of sodium borohydride now on hand. When and if this supply of borohydride is exhausted consideration can be given to securing added borohydride by open market purchase, by reactivation of the Danvers plant or by supplying borohydride (or possibly diborane) from the activated Muskogee facility. A further possibility is that before the available borohydride is exhausted, facilities could be added at Muskogee to permit producing pentaborane and decaborane from diborane at lower cost.

The uncertainties characteristic of research requirements for boron fuels dictate that the fuel needs should be met at a minimum outlay of funds. Any high-cost plan for backing up these requirements (such as starting up the 5-ton-per-day Lewiston plant) cannot be justified.

The Muskogee plant can be operated more cheaply on a continuing basis than any of the smaller plants (the 300-pound-per-day Callery plant at Lawrence, Kans., the 400-pound-per-day Olin Mathieson plant at Niagara Falls, and the 0.8-ton-per-day plant at Lewiston, N.Y.). As indicated in the above section on standby capacity, should a continuing need for boron fuels be forecast it should be met by reactivation of the Muskogee plant with facilities added for rocket fuel production. Operation of the Lewiston 0.8-ton-per-day plant beyond fiscal year 1960 should not be contemplated.

III. FUTURE RESEARCH ON BORON FUELS

The Air Force is now supporting process research and development on boron hydrides at Aerojet-Stauffer, AFN, Inc., Olin Mathieson Chemical Corp., and Callery Chemical Co. These programs were started at a time when the Air Force was considering construction of a 25-ton-per-day fuel plant. At the urging of the Joint Working Group on Special Fuels, Arthur D. Little, Inc., was engaged by the Air Force to make economic and technical feasibility studies on these alternate low cost processes for boron hydrides.

With marked reduction in the forecast requirement for boron fuels any future research should be directed toward fuel uses rather than toward manufacturing improvements. On this basis the current process improvement contracts should be terminated in an orderly fashion. Abrupt termination is not recommended because the programs are well advanced and the cost of orderly completion is small in relation to the potential savings which could result if a large need for boron fuels ever develops.

In the above connection the Arthur D. Little, Inc., process comparison study should provide guidance as to which studies should be terminated first. In any event process studies should not be extended beyond fiscal year 1960 funding.

IV. RECOMMENDATIONS

The Joint Working Group on Special Fuels makes the following recommendations:

1. The 5-ton-per-day plant at Lewiston, N.Y., be declared surplus except for items which could be used to increase the versatility of the 5-ton-per-day plant at Muskogee, Okla. Particular attention is directed to facilities which might be moved to Muskogee for manufacture of pentaborane and decaborane from diborane.

2. The Muskogee plant be placed on a standby (not mothballed) basis, following the completion of such current operations as may be needed to demonstrate operability to produce diborane. The justification for continuing the standby status of the Muskogee facility be reviewed periodically in the light of forecast needs for boran fuels.

3. Engineering studies be initiated to determine costs and other factors related to establishing rocket fuel manufacturing facilities at Muskogee. Also, studies be undertaken as to practicality and costs of supplying sodium borohydride or diborane from Muskogee for interim fuel production at the Lewiston 0.8-ton-per-day plant.

4. Current requirements for pentaborane and decaborane be met by continuing to operate the Lewiston 0.8-ton-per-day plant until a lower cost source becomes available.

5. Air Force contracts for process development research should not extend beyond fiscal year 1960 funding unless a firm requirement for fuel is established. In the event that the process comparison study now under way by Arthur D. Little, Inc., indicates one or more of the processes under development to be marginal, the earlier termination of such research contracts should be considered.

6. Consideration be given to placing cognizance for all Government-financed production of boron fuels in one service.

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[1] Not present at Sept. 10, 1959, meeting.

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